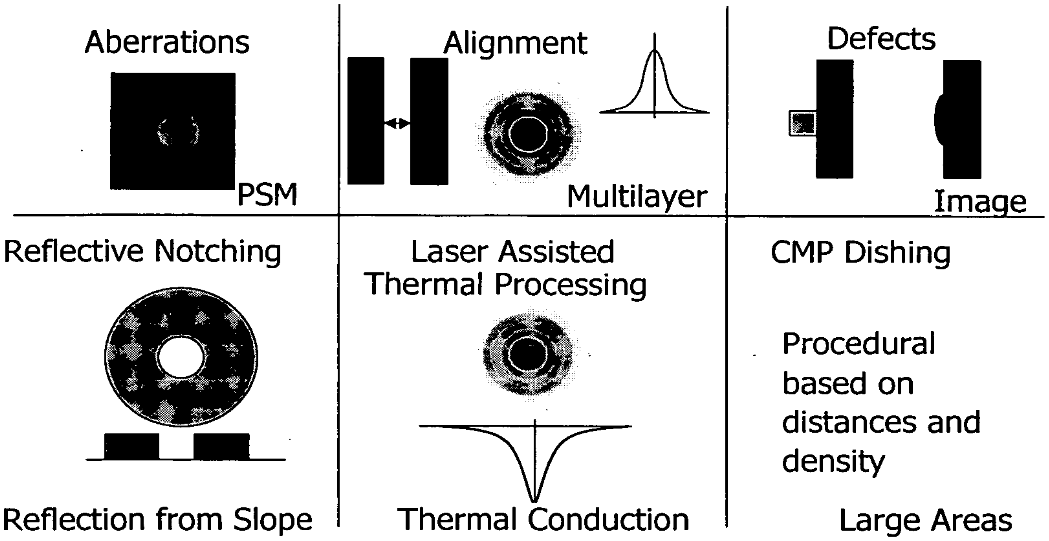

Aberrations
PSM
Alignment
Multilayer
Defects
Image
Reflective Notching
Reflection from Slope
Laser Assisted Thermal Processing
Thermal Conduction
CMP Dishing
Procedural based on distances and density
Large Areas

FIG. 1

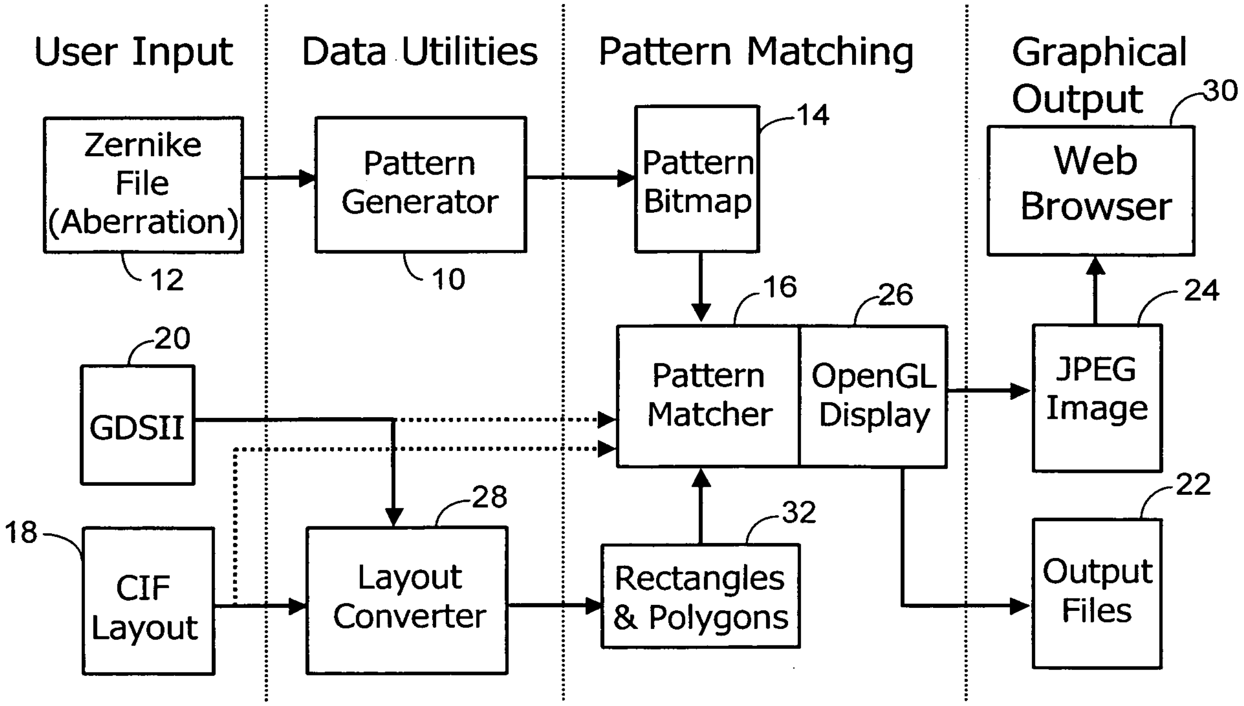

User Input
Data Utilities
Pattern Matching
Graphical Output
Zernike File (Aberration)
12
Pattern Generator
10
Pattern Bitmap
14
Web Browser
30
GDSII
20
Pattern Matcher
16
OpenGL Display
26
JPEG Image
24
CIF Layout
18
Layout Converter
28
Rectangles & Polygons
32
Output Files
22

FIG. 2A

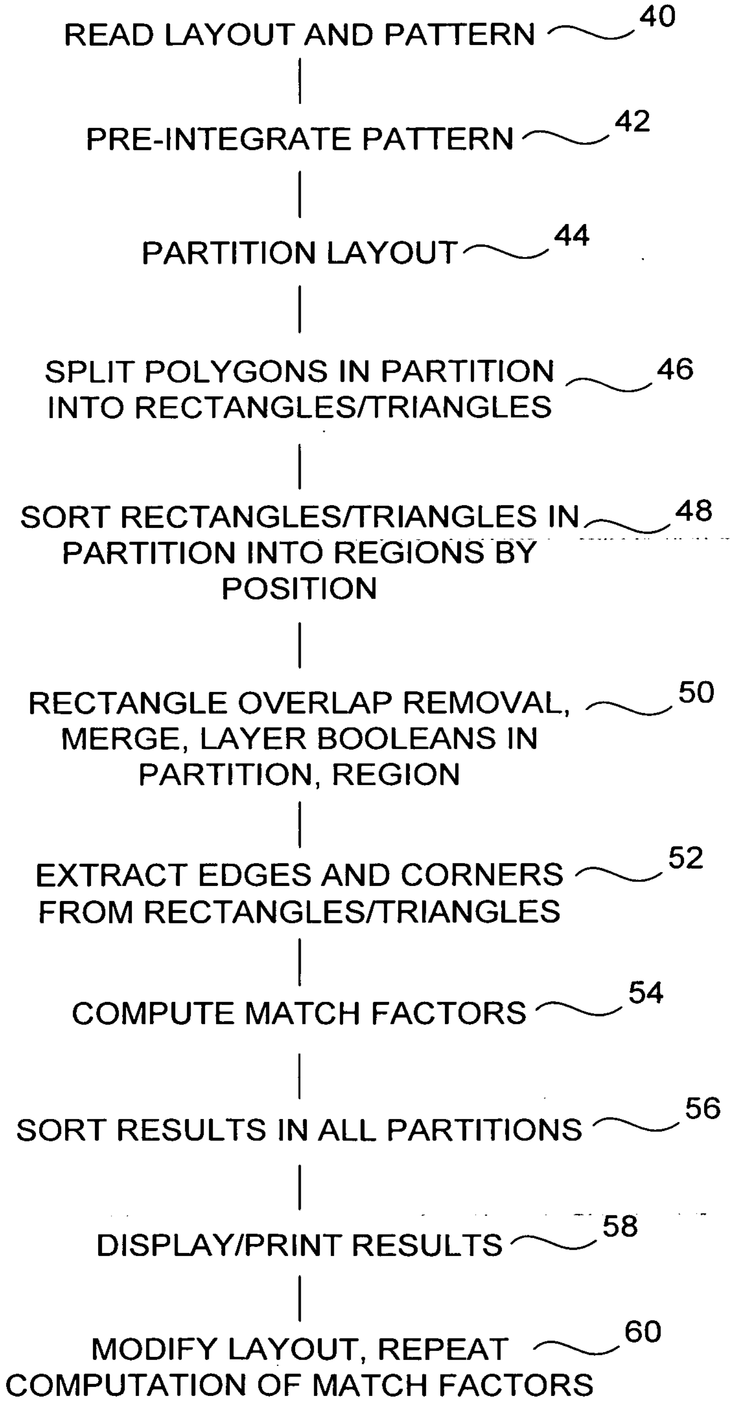

READ LAYOUT AND PATTERN
40
PRE-INTEGRATE PATTERN
42
PARTITION LAYOUT
44
SPLIT POLYGONS IN PARTITION INTO RECTANGLES/TRIANGLES
46
SORT RECTANGLES/TRIANGLES IN PARTITION INTO REGIONS BY POSITION
48
RECTANGLE OVERLAP REMOVAL, MERGE, LAYER BOOLEANS IN PARTITION, REGION
50
EXTRACT EDGES AND CORNERS FROM RECTANGLES/TRIANGLES
52
COMPUTE MATCH FACTORS
54
SORT RESULTS IN ALL PARTITIONS
56
DISPLAY/PRINT RESULTS
58
MODIFY LAYOUT, REPEAT COMPUTATION OF MATCH FACTORS
60

FIG. 2B

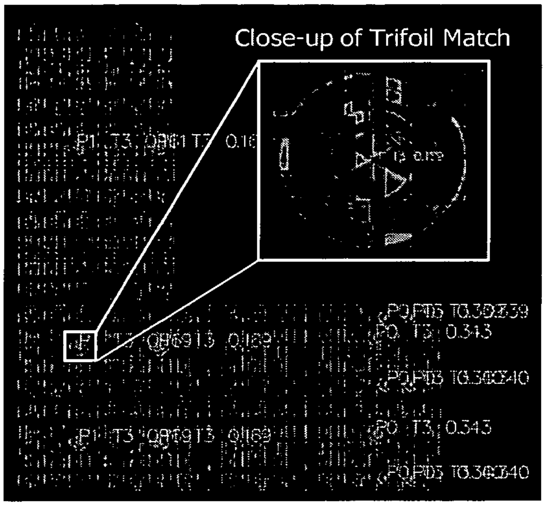

Close-up of Trifoil Match
P1 T3 0.161 T3 0.16
T3 0.179
T3 0.169 T3 0.169
P0 T3 0.339
P0 T3 0.343
P0 T3 0.340
P0 T3 0.343
P1 T3 0.169 T3 0.169
P0 T3 0.340

FIG. 3

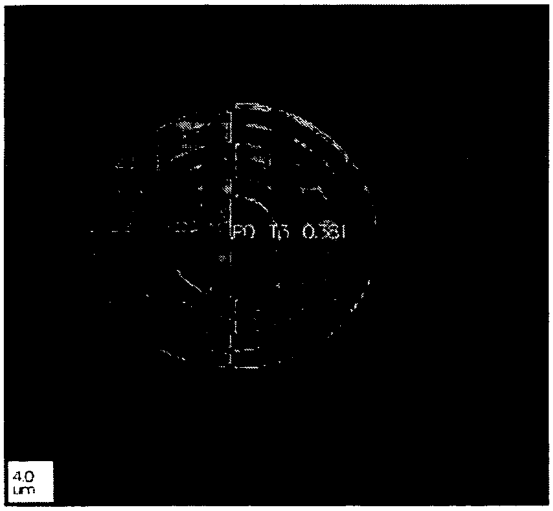

P0 T3 0.381
4.0 um

FIG. 4

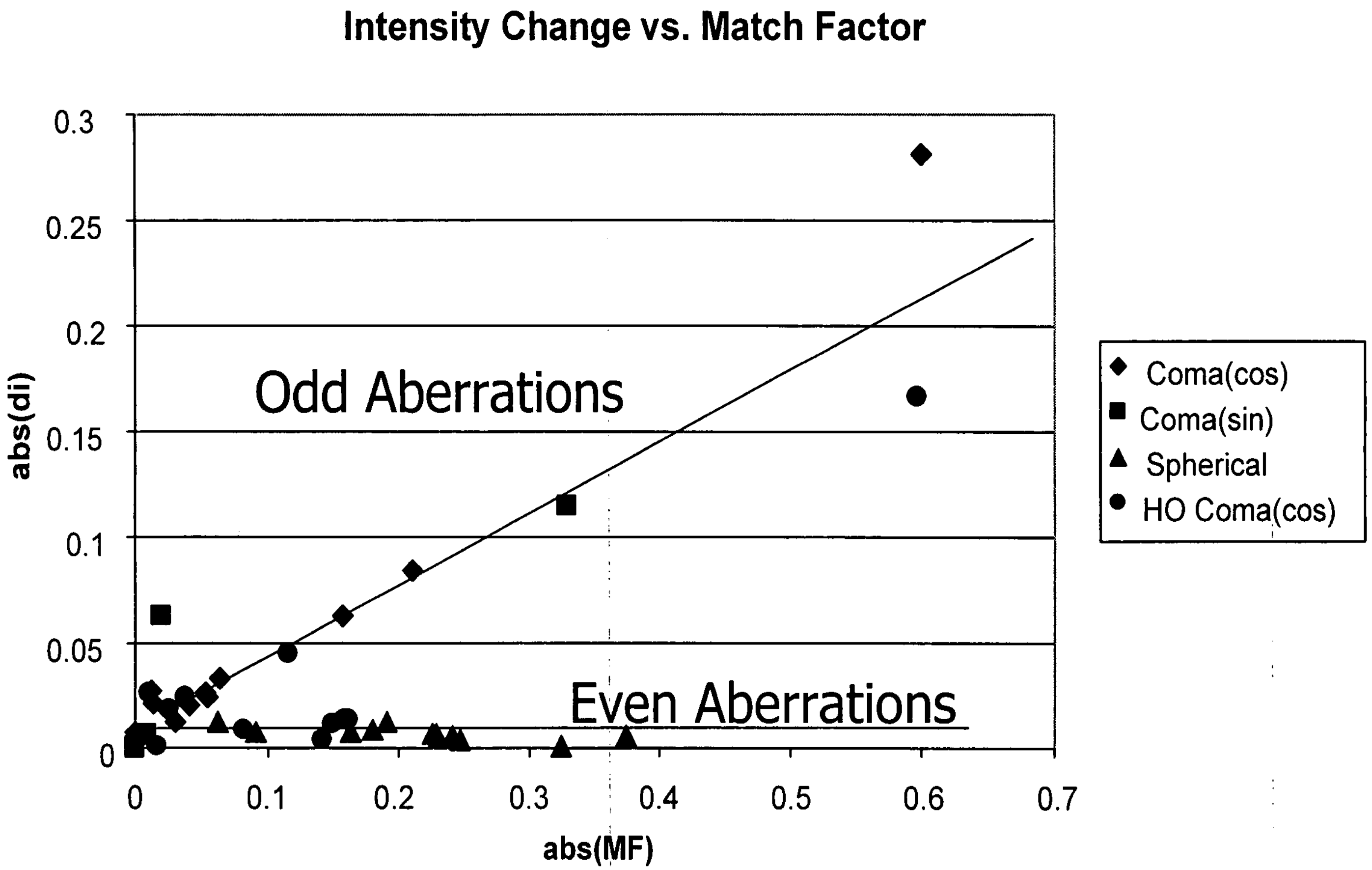

Intensity Change vs. Match Factor
abs(di)
0.3
0.25
0.2
0.15
0.1
0.05
0
Odd Aberrations
Even Aberrations
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
abs(MF)
◆ Coma(cos)
■ Coma(sin)
▲ Spherical
● HO Coma(cos)

FIG. 5

Generic Pattern Matching Code

1. Divide input shapes (polygons) into geometric primitives

2. Spatially organize primitives by x, y, etc.

3. Compute Match Factor (MF):

```
for each pattern P
    for each orientation of P
        for each match type T
            for each X,Y match location
                for each geom. Primitive G overlapping P
                    add contribution of G on P at X,Y to MF
```

Time dominated by #3: #patterns x #orientations x #types x #locations x #primitives_overlap_pattern x time(primitive)

FIG. 6

Data Structures

- Input = polygons, rectangles (special case of a polygon), paths (can be converted to polygons), and circles (can be approximated by many-sided polygons) = polygons
- Geometric Primitives:

Type	Number in layout	Operations to add to MF (time)
Pixel (Bitmap Alg.)	Very Large (area)	1
Edge Intersection	Large (perimeter)	2
Rectangle	Medium	4
Triangle	Small (or none)	4 to 12 (if split)

- Higher-level primitives (lower in table) are much more efficient to store and use

FIG. 7

Polygon Splitting (Bitmap)

- Manhattan Polygon => Bitmap
  - Too many pixels to store – large blocks of the same value

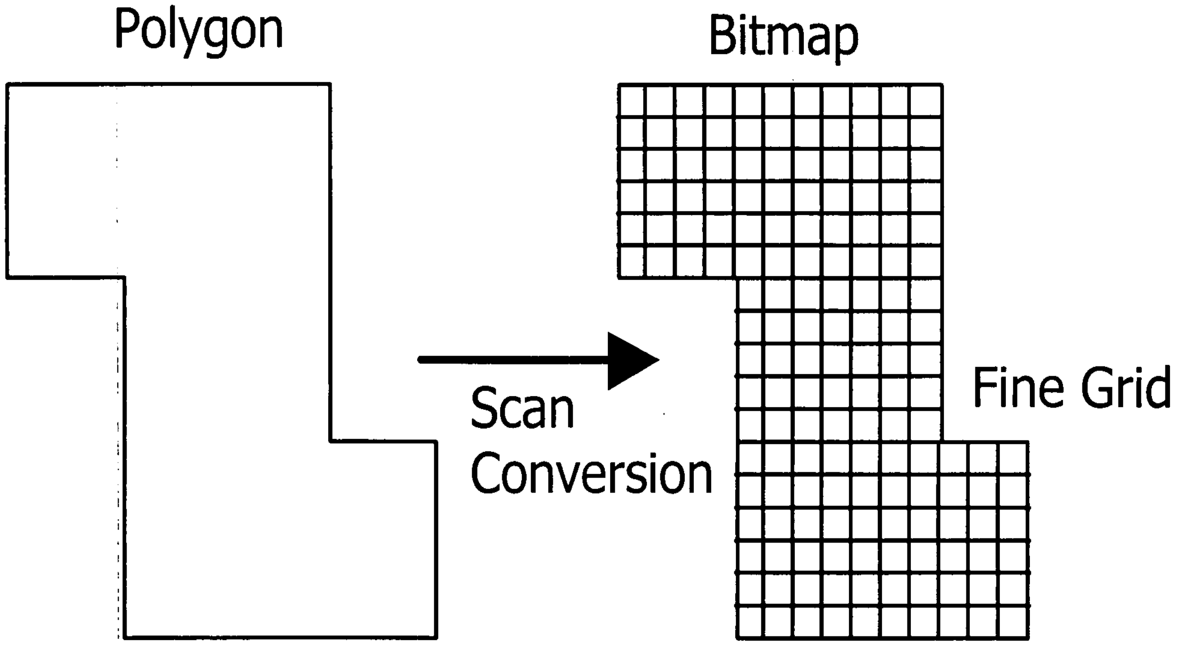


FIG. 8

Polygon Splitting (Edges)

- Manhattan Polygon => Edges
  - Well, actually rectangle strips between 2 edges

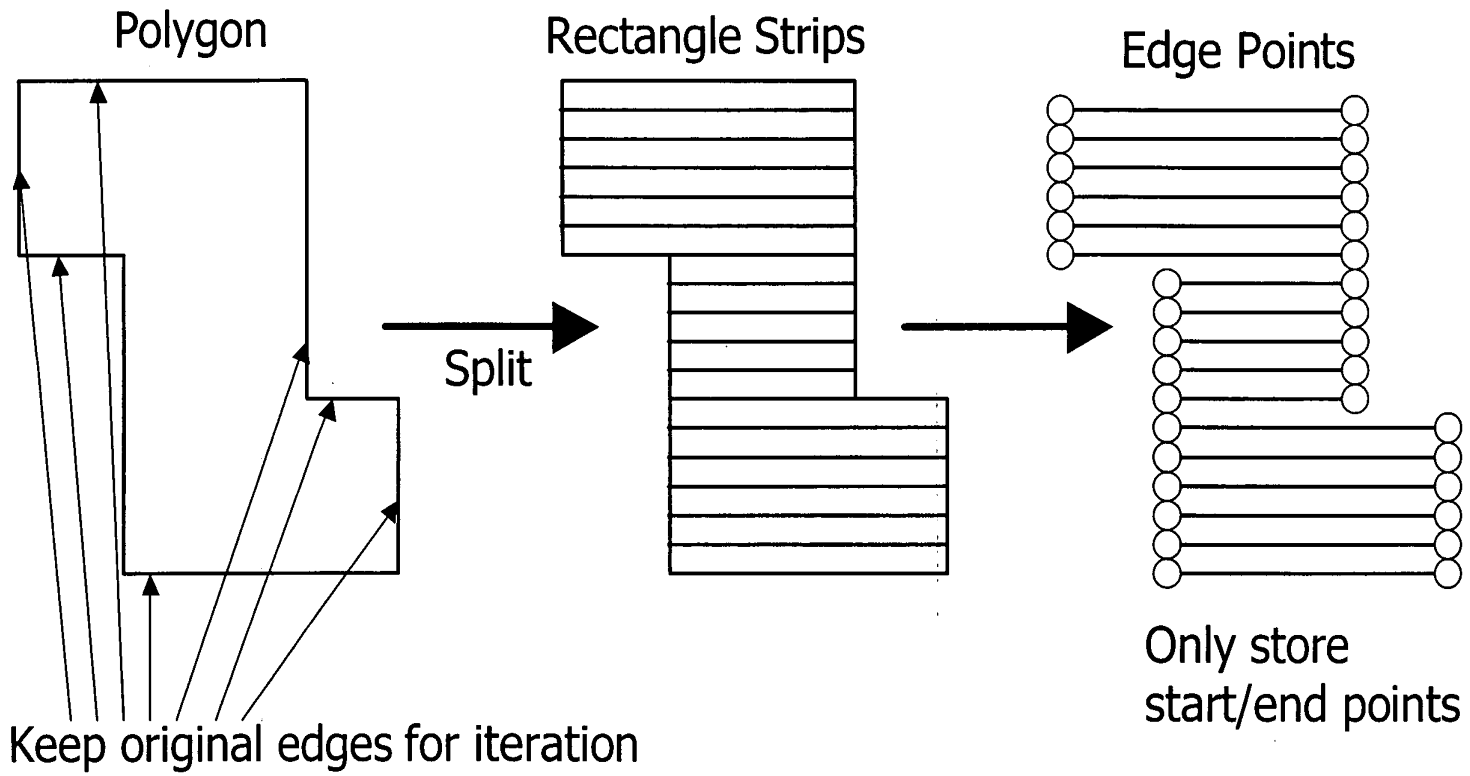


FIG. 9

Polygon Splitting (Rectangles)

- Manhattan Polygon => Rectangles

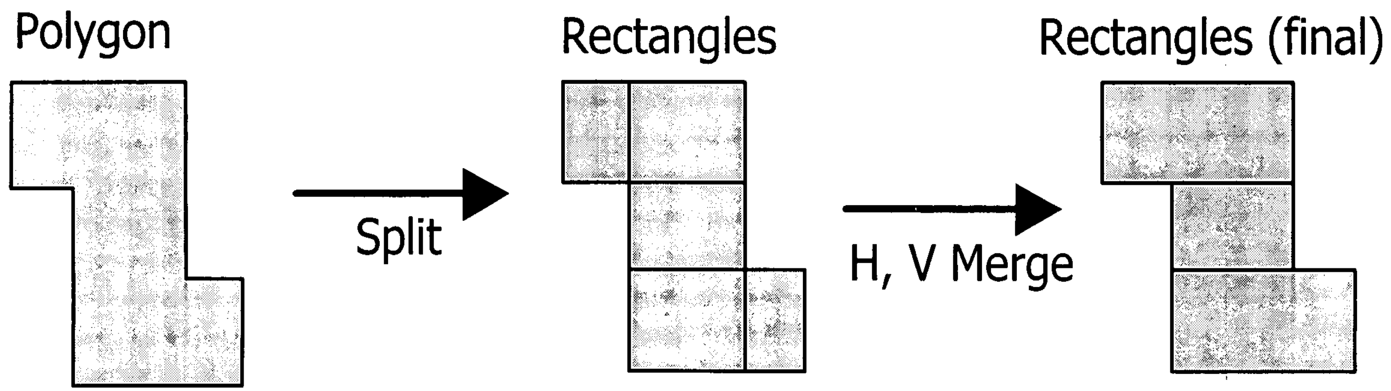


FIG. 10A

- Non-Manhattan Polygon => Rectangles

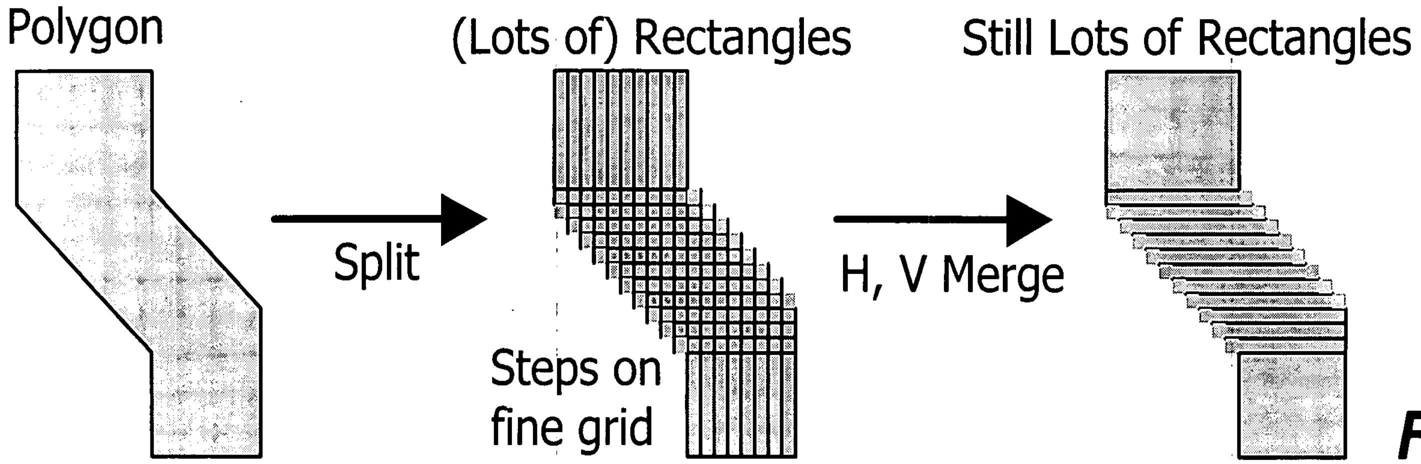


FIG. 10B

Polygon Splitting (Triangles)

- Non-Manhattan Polygon => Rectangles + Right Triangles

Primary Goal: Min # Triangles
Secondary Goal: Min # Rectangles

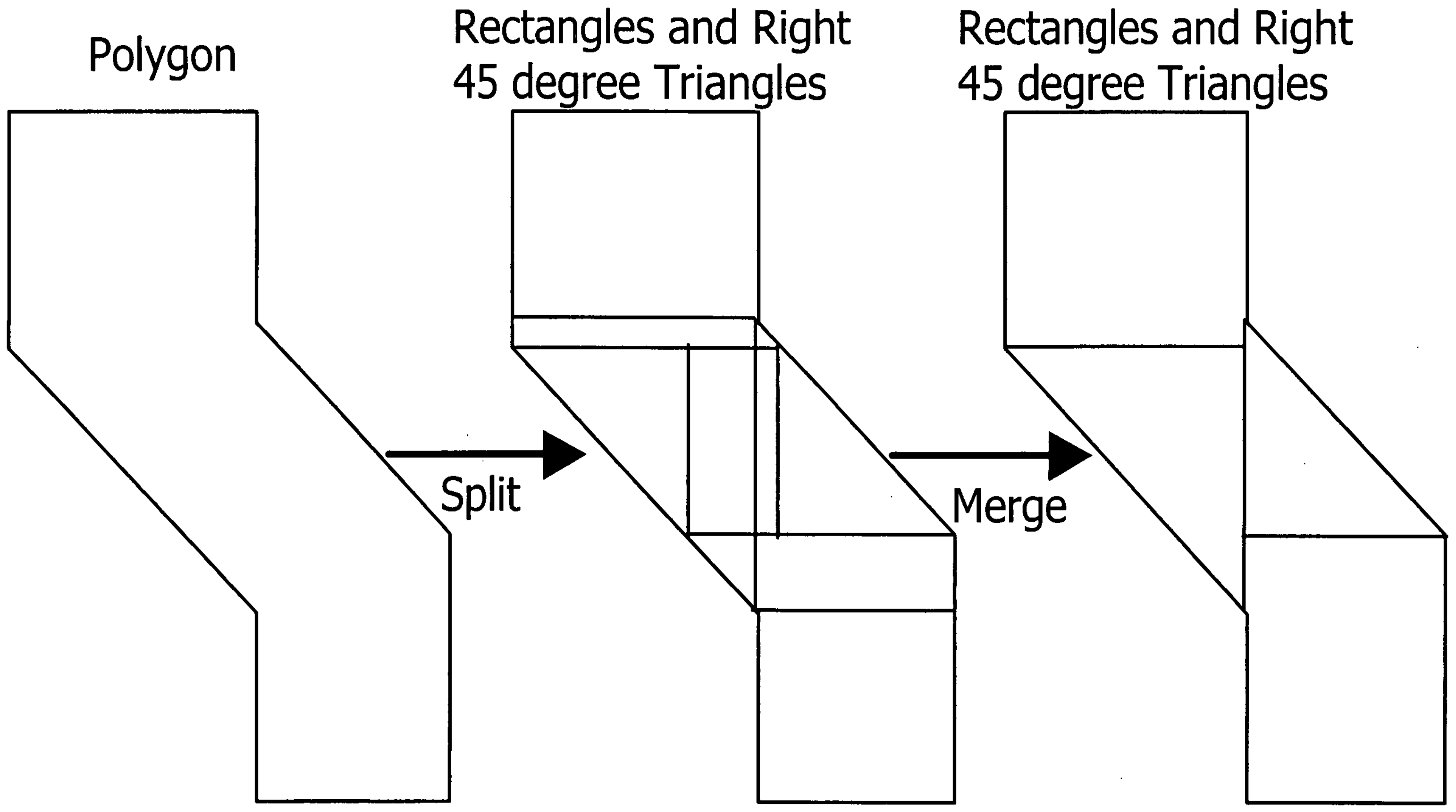


FIG. 11

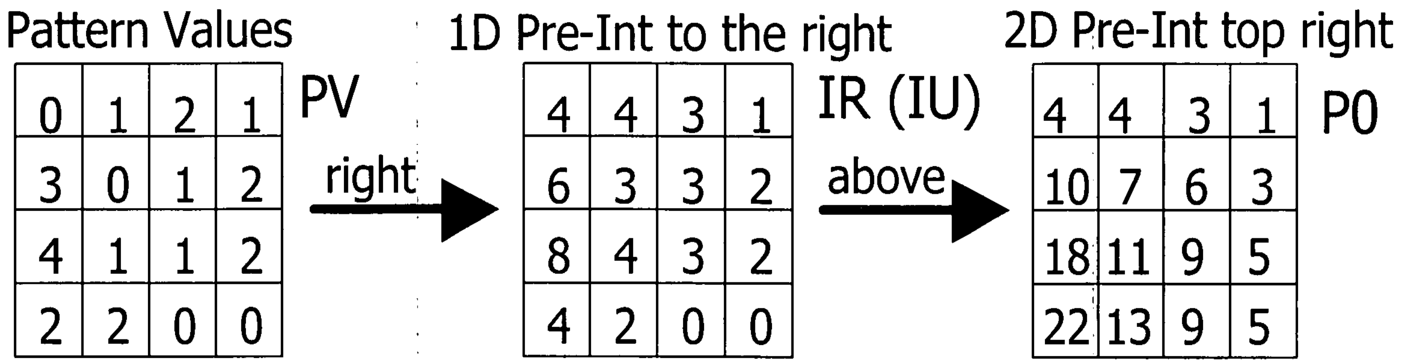
Pattern Pre-Integration

- 1D Pre-Integration
  - Can be horizontal or vertical, either will work
  - Pre-integrated value = sum of all pattern values at and to the right

Pattern values	0	1	2	1	3	0	1
Pre-int values	8	8	7	5	4	1	1

- 2D Pre-Integration
  - Starts with 1D pre-integration
  - Pre-integrated value = sum of all pattern values at and to the right AND above (top right = orientation P0)

Typical PM pattern is 128x128



Pattern Values

0	1	2	1
3	0	1	2
4	1	1	2
2	2	0	0

PV

right

1D Pre-Int to the right

4	4	3	1
6	3	3	2
8	4	3	2
4	2	0	0

IR (IU)

above

2D Pre-Int top right

4	4	3	1
10	7	6	3
18	11	9	5
22	13	9	5

P0

FIG. 12

Algorithm 1: Bitmap

- Entire layout represented as one huge bitmap of layers (like images on a computer screen)
- One rectangle is added at a time to the bitmap
- At every match location (edge, corner, etc.), each pattern pixel is multiplied by the layout pixel and summed:

$$MF(i+\frac{X}{2}, j+\frac{Y}{2}) = norm * \sum_Y \sum_X Layout(x+i, y+j) * Pat(x,y)$$

- Pattern size (X by Y) is typically 128x128 = 16384 ops

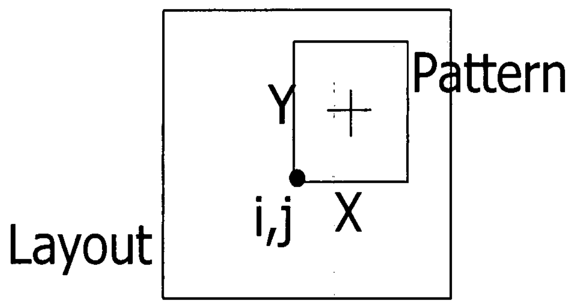


FIG. 13

Algorithm 2: Edge Intersections

- Store only the pixels along edges
- Run-length encoding in 1D – skip large runs of the same pixel value (rectangle strips)
- Pre-integrate pattern in 1D: $val(i,j) = \sum_{k=i}^{X} pat(k,j)$ for x intersection case
- Add MF contributions from each rectangle strip between two edges (either X or Y dir)

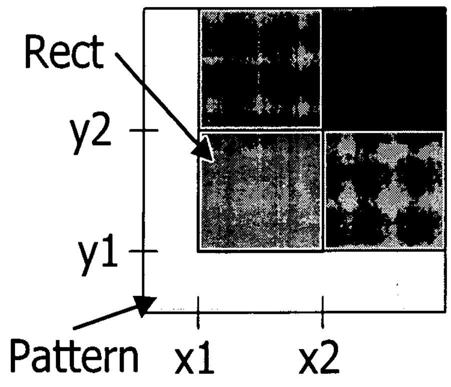
pat(…,j)	0	1	2	1	3	0	1
val(…,j)	8	8	7	5	4	1	1
r strip (weight 1)		1				-1	
		+	edges			-	

Contribution:
$1*8 + (-1)*1 = 7$

FIG. 14

Algorithm 3: Rectangles

- Simplest data structure: Store only the rectangles and pointers to them
- 2D encoding – only rectangle corners are needed
- Pattern integrated in 2D, rectangle LL corner clipped to pattern area
- Integrated pattern value is sum of values above and to the right: $val(i,j) = \sum_{k=i}^{Y} \sum_{l=j}^{X} pat(k,l)$



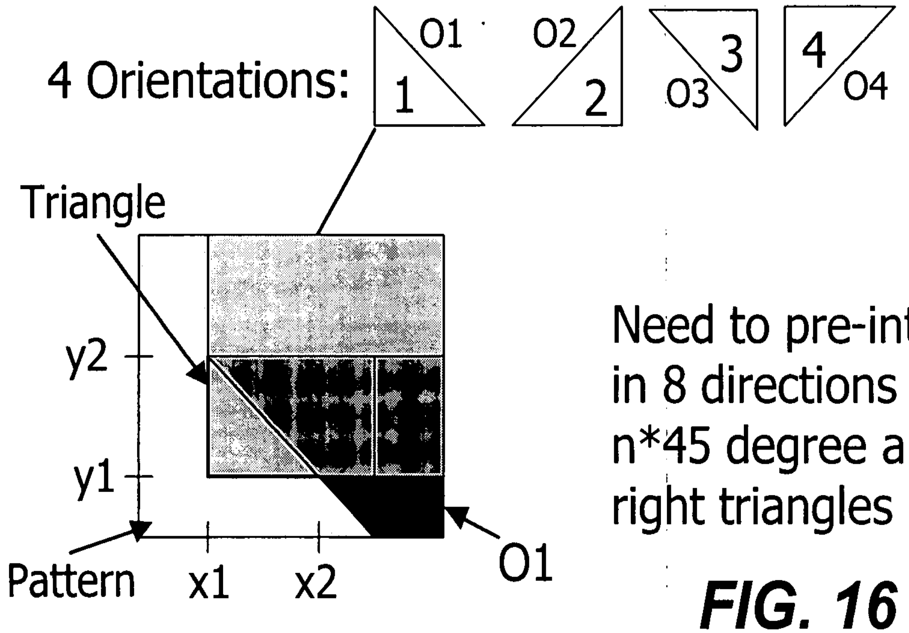
Contribution from rect at (x1,y1), (x2,y2) =
val(x1,y1) – val(x2,y1) – val(x1,y2) + val(x2,y2)

Only process LL corner and other 3 if inside pattern

FIG. 15

Algorithm 3b: Triangles

- Extension of rectangle algorithm
- Pre-integration time/storage proportional to the number of unique angles
    - Limited to multiples of 45-degree angles in practice
        - 0, 45, 90, 135, 180, 225, 270, 315 deg => 8 preintegrations



Need to pre-integrate in 8 directions for n*45 degree angled right triangles

Triangle clipping is difficult

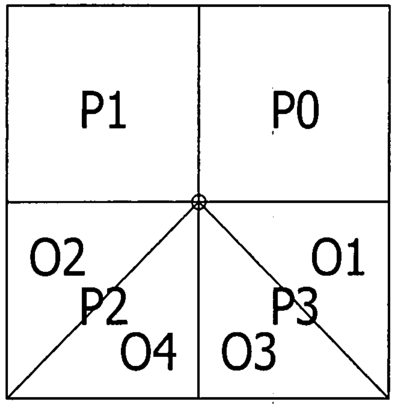


FIG. 16

Rectangle/Triangle Clipping

Rectangle => Rectangle

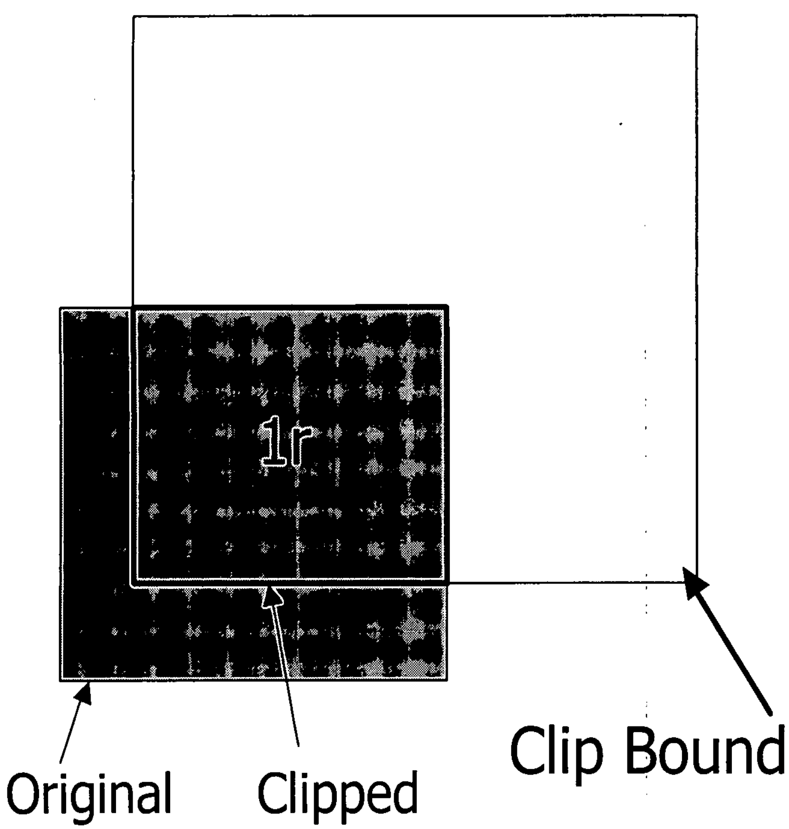
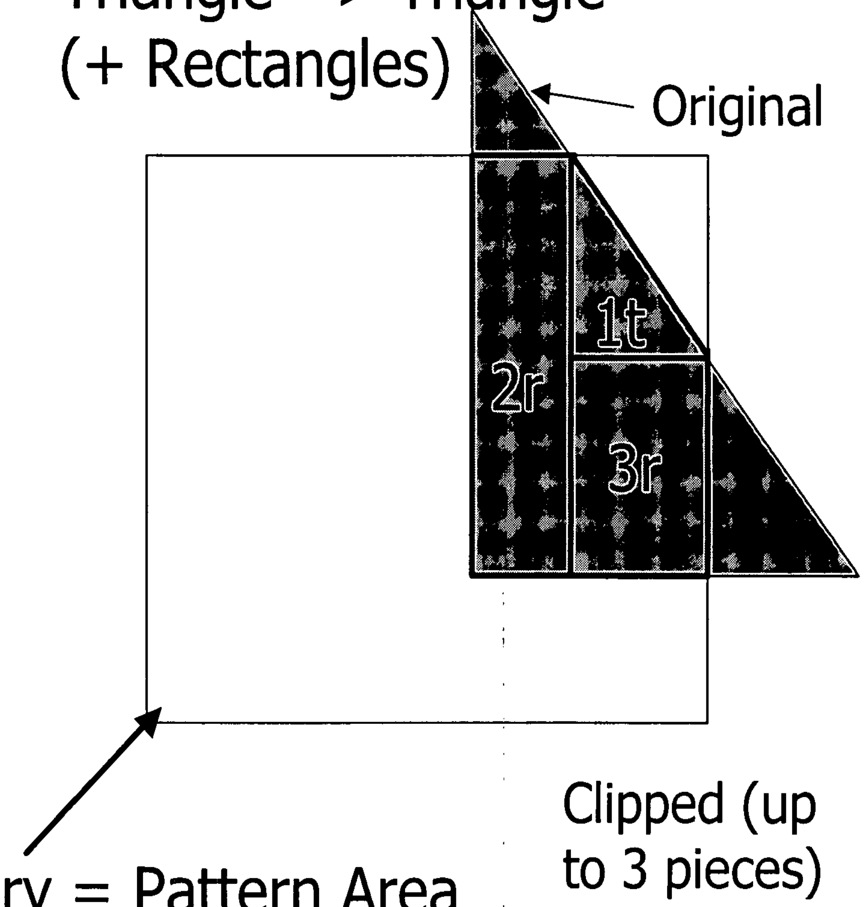


FIG. 17A

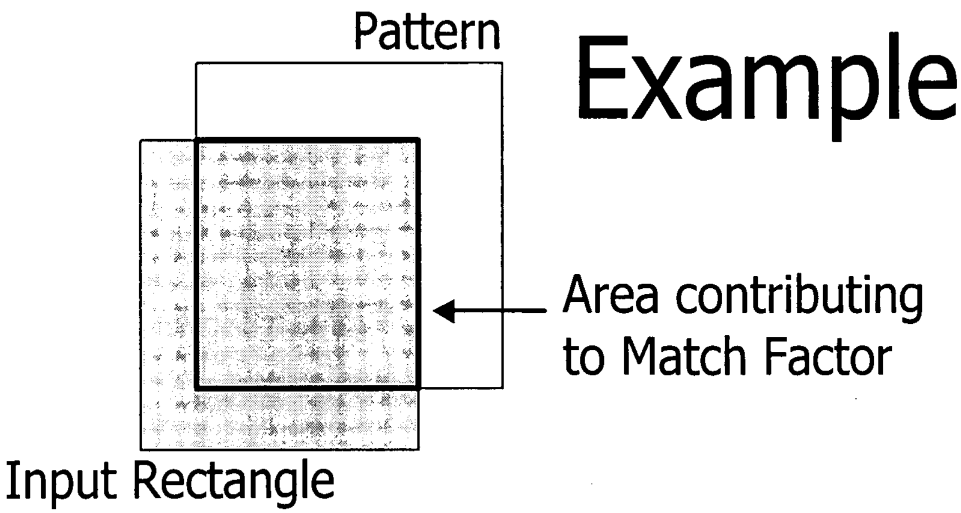
Triangle => Triangle
(+ Rectangles)



Clip Boundary = Pattern Area

FIG. 17B

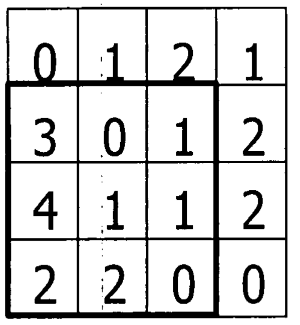
Examples



RL = rectangle length (3)
RH = rectangle height (3)
TL = triangle length (3)
TH = triangle height (3)

Bitmap Algorithm

Pattern Values



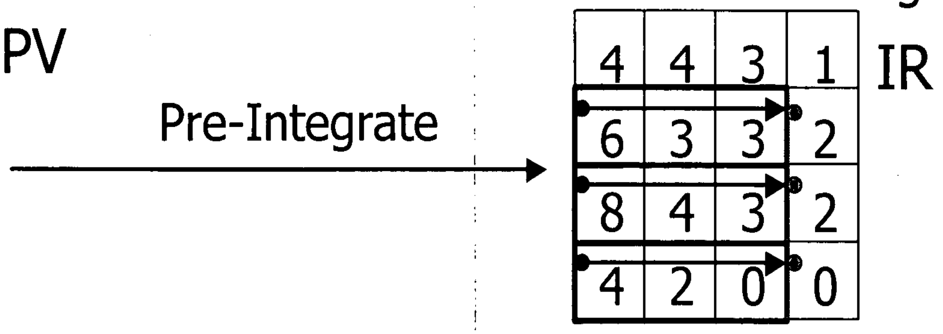
0	1	2	1
3	0	1	2
4	1	1	2
2	2	0	0

(3+0+1) + (4+1+1) + (2+2+0) = 14
RL*RH = **9** Operations

FIG. 18A

Edge Intersection

1D Pre-Int to the right

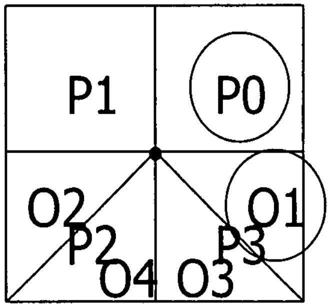


4	4	3	1
6	3	3	2
8	4	3	2
4	2	0	0

(6-2) + (8-2) + (4-0) = 14
2*RH = **6** Operations

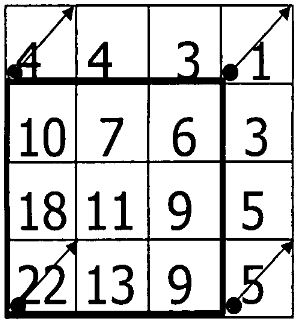
FIG. 18B

Examples



Rectangle Algorithm

2D Pre-Int top right



4	4	3	1
10	7	6	3
18	11	9	5
22	13	9	5

P0

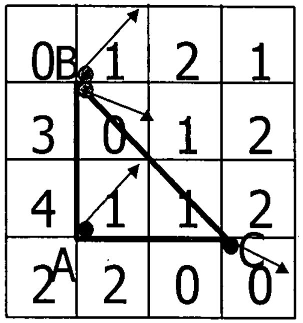
LLC – ULC – LLC + URC =
22 – 4 – 5 + 1 = 14
Always **4** Operations

45-Triangle Algorithm

8-way Pre-Int → Precomputed:

P0 from rect algorithm

Pattern Values



0	1	2	1
3	0	1	2
4	1	1	2
2	2	0	0

PV

O1(B) = 1+2+2+
(0+1+0)/2 = 5.5

O1(C) = 0/2 = 0

P0(A) – P0(B) – O1(B) + O1(C) =
11 – 4 – 5.5 + 0 = 1.5
4 Operations/Shape (12 max)

FIG. 19

Examples

1D Pre-Int to the right

IR

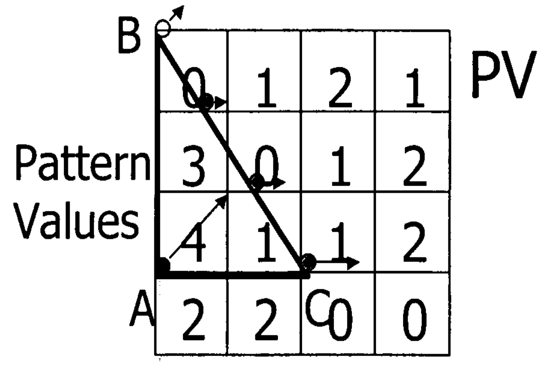
4	4	3	1
6	3	3	2
8	4	3	2
4	2	0	0

2D Pre-Int top right

P0

4	4	3	1
10	7	6	3
18	11	9	5
22	13	9	5

Non-45 degree Triangle (Proposed)



P0(A) – P0(B) – IR(B...C) =
18 – 0 – (4 + 3 + 3) = 8
TH + 2 = **5** Operations

Similar to edge intersection
algorithm but reduced storage

FIG. 20

Data Structures and Algorithms

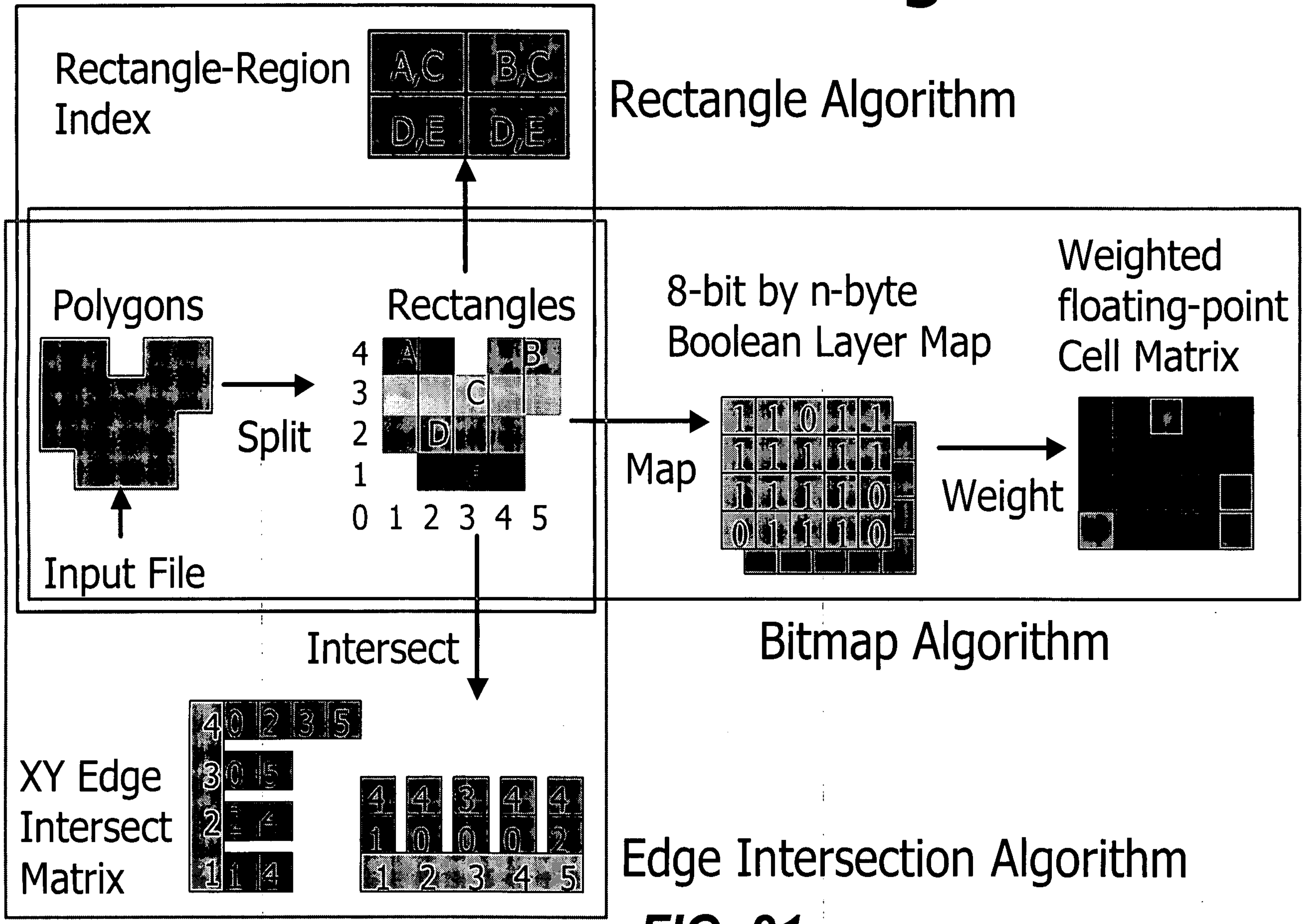


FIG. 21